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ABSTRACT

In order to facilitate library collection management at West Virginia University (WVU), information was collected on the journals cited in the 87 doctoral dissertations written by students in the WVU College of Engineering during a 7-year period ending in 1978. This analysis followed a similar citation study of WVU engineering master's theses accepted in 1971-1974, which had led to a significant reduction in expenditures for engineering subscriptions. It was found that citation patterns in the doctoral and master's theses were similar; WVU doctoral engineering students cited journals in only 43% of their references; a core of 51 of the 585 journals cited accounted for one-half of the journal citations; 81% of the cited journals were cited by authors from only a single engineering department; and the citation of non-engineering journals by engineers was not extensive. Results are discussed in terms of specific collection management decisions at WVU. It is noted that WVU funding for engineering journals far exceeds the amounts needed to purchase the core journals and that choosing among the other marginal use journals remains a matter of judgment on the part of librarians and faculty. A 35-item bibliography and tables listing study results are provided. (ESR)

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LIBRARY MANAGEMENT IMPLICATIONS OF JOURNAL CITATION PATTERNS IN ENGINEERING DOCTORAL DISSERTATIONS

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PREFACE

Several years ago I prepared a report entitled Research Journals for the Master's Program in Engineering at West Virginia University. That work described a study of the journals cited in engineering master's theses accepted by the WVU College of Engineering between 1971-1974. It was necessary at that time to examine critically the use of library materials so that limited financial resources could be applied most effectively toward continued development of WVU's collections in the field of engineering.

My study of master's theses had significant effects on the WVU engineering collections. Expenditures for engineering subscriptions at WVU were reduced from $25,000 in 1973 to $23,000 in 1976. During that same period, the average price of an engineering subscription increased by about 50%, while the WVU Libraries increased total subscription expenditures by 34%. Cancellation of subscriptions to periodicals which exhibited little if any use made possible the continued purchase of high use periodicals. More importantly, cancellations made possible the continued development of a strong book collection.

In 1975, few librarians were attempting to use objective, quantitative data to manage collections. Indeed, today's fashionable term "collection management" was almost never heard. Citation studies were viewed as academic exercises for studying science, although Eugene Garfield had been arguing the benefits of practical applications for some time. Certain-

ly the cancellation of subscriptions to maintain book buying was an action opposite to that taken by most libraries accustomed to operating under the assumptions fostered by earlier, uncritical speculations about collection use.

Today, austerity is a way of life for research libraries. Even the wealthier institutions have had to search for defensible ways to allocate limited resources in the face of open ended demands. The art of collection development is evolving into the practice of collection management as more librarians seek data on which to base informed decision making. The creation of the journal Collection Management in 1976 reflects the existence of attempts to find new concepts to guide library managers.

With the reality of limited funding finally becoming obvious at even the highest levels of the ivory tower, it is more important than ever that libraries obtain objective, quantitative data on the use of collections. Libraries are, after all, in competition with many other units of the university in seeking funds for their goals. More importantly, librarians have a professional and ethical obligation to the taxpayers to spend the funds entrusted to them in responsible ways. Simple self-interest should drive librarians to consider the effect on academic administrators of the widely publicized controversy surrounding Allen Kent's study of book use at the University of Pittsburgh. Surely many administrators have not missed the point that substantial reductions in library funding can be defended on the basis of the Pitt data.

The work described in this report extends my study of master's

theses in engineering to dissertations written by engineering Ph.D. candidates at WVU during a 7-year period in the 1970s. Reasons for extending the study are apparent. For example, librarians and faculty commonly assume that the library resources required for Ph.D. programs far exceed those required for master's programs. This assumption can now be tested for the field of engineering. Further, this study covers a time period almost twice as long as the master's study, so that the data are averaged over any changes in research interests which may have occurred during the 1970's. Finally, since this study covers several years following WVU's major engineering subscription cancellation effort in the mid-1970s, it may be possible to detect and correct any errors resulting from the more limited data of the master's study.

Some faculty and librarians will argue that studies such as this one should not be done because of the danger that the data acquired may fall into the wrong hands. Indeed, the University of Pittsburgh's Executive Council for Libraries argued against the Pitt Study on precisely these grounds. Arguments about the danger of research seem especially inappropriate when presented by those who have devoted their lives, or at least their careers, to the pursuit of knowledge. In any case, ignorance of the facts will prove even more dangerous, as has been discovered by those librarians who postponed decisions and argued against quantitative data until their entire acquisitions budgets were consumed by the cost of serials.

It is worth remembering that the existence of data about collection use is not what drives collection management decisions. Journals are not

canceled because of low use. Instead, management decisions are driven by budgets. Subscriptions are canceled when it is decided that limited funds can be used more effectively for the purchase of library materials other than journals. These decisions about library funding will be made with or without information. When information is gathered, it will be interpreted either by those who understand it or by those who do not. How much better for the future of libraries if information about the use and value of information should be gathered and interpreted by those best qualified to assess the implications.

INTRODUCTION

Engineering education in the early 1970s shared in the austerity brought on by inflation, declining enrollments, the energy crisis, and reduced university budgets. Now added to these problems are those caused by high demand for engineers in industry (which is causing both students and faculty to leave the universities) and by rapidly increasing enrollments (which strain limited fiscal and physical resources). Popular news magazines have publicized these problems, which are discussed often in academic literature.[1-9] Usually not mentioned in the literature are the problems faced by engineering libraries.

Years of inflation have had a profound effect on academic libraries. From 1978-1980 alone, prices of scientific and technical books rose by 48%. Journal subscriptions have continued to rise in price by 10-20% each year for at least a decade.[10, 11] Library budgets have no more kept pace with these increases than have faculty salaries kept pace with the consumer price index. The resulting decline in the traditional measures of library quality (for instance, size and rate of growth) have remained largely invisible to faculty, students, and university administrators. Librarians have adjusted to budget realities with little discussion of the results, an approach which may yet have serious consequences for the profession.[12]

In some cases it may be that appropriate decisions in response to funding shortfalls have simply eliminated the enormous waste implied by

the results of the Pitt study.[13] However, most decisions have been made without the hard data which engineers and business managers assume to be necessary in planning. Indeed, it has been argued that misunderstandings about the nature of academic research still guide collection management decisions.[14] Assumptions and preconceptions developed during prosperous times when collection development was an art practiced for its own sake persist among librarians to this day. This is unfortunate, for the major problem in collection management is to decide what is unnecessary and what is no longer useful.

Drucker's concept[15] of "sloughing off yesterday" will characterize the efforts of those libraries seeking to serve the future. A major source of capital for the purchase of new books and journals will be the systematic abandonment of that which has proven unnecessary and of that which is no longer useful. Indeed, the savings realized from cancellation of unnecessary subscriptions easily can exceed the annual increase in a library's total acquisitions budget. These savings will be realized each and every year, not just during the year of cancellation, just as noncancellation of a subscription implies a continuing cost in each and every subsequent year.

In examining the use of journal literature by engineering Ph.D. candidates at West Virginia University (WVU), this study seeks information necessary for informed decision making which will guide the development of WVU's library collections and maintain the ability of the library to support WVU's programs.

METHOD

Several approaches to the study of journal use are possible. Each approach involves defining a quantifiable measure of use and selecting a measure of minimum library service. Use can be defined in terms of the in-library use of journals,[16, 17] or in terms of citation frequency of journals used by faculty in their publications[18] or by students in their theses.[19-22] Each of these methods provides a measure of the use of journals by the users of a particular library. Citation counts of journals in Ph.D. dissertations is the measure of use chosen for this study.

Alternatives are possible in studying use, although the alternatives measure what might better be called potential usefulness. One method counts the number of times a particular journal appears in a secondary publication covering the subject field in question.[23] This approach is much easier than carrying out a use study or a citation study, but it can determine only the number of articles a particular journal publishes in a field. Another method uses the data available in Journal Citation Reports to rank journals according to importance in the world's scientific and technical literature. Both techniques are useful methods of studying characteristics of the literature as a whole. Neither provides a measure of use patterns in a particular library or by a particular group of users. Brookes[24, 25] has emphasized the uniqueness of each library and its users. Line[26] argues that to have any significant practical value to libraries journal use measures must be based on local use studies.

Clearly, few universities have such large departments in any one field that all possible interests in the literature of that field will be represented. Limits on library funding imply the need to evaluate the limits of research interests among the local group of library users.

Several specific reasons can be given for the importance of local use studies.[21] To review briefly:

1. The library must serve its users, not a subject field.

2. Needs of specific user groups can differ markedly from the needs of the average user.

3. Educational use in academic libraries may be quite different from use by professionals in a field.

4. Use variation by subfield must be taken into account when balancing conflicting needs of different academic departments.

5. Long-term development of academic research collections requires time-averaged use measures.

In principle, levels of service should be defined in terms of a cost-benefit analysis. In practice, the librarian must take into account numerous noneconomic factors. Quantifying inconvenience, relative value of subject fields, and political considerations is all but impossible. Benefits must be defined primarily by the judgment of librarians and users.

This is not to say that use studies can have no practical value. It must simply be recognized that use studies inform judgment, but they do not provide incontrovertible proof of anyone's opinion. It will be seen from the data in this study that sharply defined levels of usefulness do exist, but that within levels the citation data alone provide no criteria for determining relative usefulness. As Line pointed out,[26] among journals of marginal usefulness, chance becomes an increasingly important factor in determining relative importance in terms of citation data.

The limitations of this study should be held in mind. First, only journals used by Ph.D. candidates in engineering at WVU are examined. Use of journals by faculty has not yet been studied. However, since faculty publications are heavily dependent on the collaboration of graduate students, combined results of the doctoral and masters studies should provide a broad measure of the need for journals to support WVU's engineering programs. Second, the particular journals found useful at WVU reflect particular research interests at WVU. Similar patterns of use in terms of the number of journals used might be expected at other engineering schools, but this expectation must be tested. Third, implicit in a citation study is the assumption that all needed articles were obtained. Obviously it cannot be determined how many articles might have been of interest but could not be obtained either locally or through interlibrary loan.

The validity of citation counting as a means of determining information sources used by doctoral candidates may be questioned. Every librarian knows that many periodicals are widely read but never cited. It must

also be true that those periodicals which are never read are never cited. Thus, the results of citation analysis cannot prove that any particular journal is of no use. However, the results can provide useful data on which to base decisions, and they can call attention to the need to reexamine assumptions and preconceptions.

Citation analysis has found extensive application in bibliometrics, faculty evaluation, and library management. The serious student will want to read Garfield's book.[27] A recent review by Smith[28] summarizes the technique and its uses, while Koenig[29] explores its developing use in the arts and humanities. Articles by Garfield[30] and Wade[31] provide useful short introductions to the subject.

DATA COLLECTION

All references in the 87 Ph.D. dissertations written by students in the WVU College of Engineering during the 7 years ending in 1978 were examined. Citations to journal articles were tabulated and sorted into several categories. As in the earlier study of citations in master's theses, a journal was defined as a serial publication issued at regular, specified intervals on at least a quarterly basis. This definition corresponds to the library user's general idea of what constitutes a magazine or periodical, but it excludes certain forms of publications which some users think of as journals. In particular, proceedings and transactions of some professional societies were excluded from consideration.

Journals which have ceased publication, have changed title, or have been absorbed by other journals, were tabulated under the title as published. This corresponds to the now common library practice of cataloging serials by successive entry. Listing journals by latest title would cause minor changes in the citation frequency of some journals, but it would leave unchanged the general conclusions of this study.

RESULTS AND DISCUSSION

Total Citations

Table 1 presents a summary of data relating to the total number of citations to all types of information sources used by the authors of the 87 Ph.D. dissertations. The data show the distribution of dissertations among the six engineering departments. These departments are Aerospace (AE), Chemical (ChE), Civil (CE), Electrical (EE), Industrial (IE), and Mechanical (ME).

There were 5,860 citations in the 87 dissertations. This is an average of 67 references per dissertation, but the range extended from a low of 12 references in AE and CE dissertations to as many as 434 references in a ChE dissertation. Half of the authors cited at least 58 different sources of information.

The average and median number of references in the Ph.D. dissertations are nearly 3 times greater than the average and median for master's theses. This may result in part from the greater depth and scope of doctoral research, but the requirement by some advisers for an extensive literature review also is a factor. Citations to Newsweek, Time, and The Holy Bible were among those found in background essays introducing the subjects of the dissertations.

As was found for the master's theses, students in ChE, CE, and IE tend to use more sources of information than do those in AE or EE. Doctoral students in ME use proportionately more sources of information than do master's candidates in ME.

Journal Citations

Table 2 summarizes data on journal citations. The 87 dissertations contained 2,494 citations to journals. Hence, only 43% of all references in the engineering Ph.D. dissertations cited journals. Indeed, in every field of engineering except ChE, the percentage of references which cited journals is below 50%. The remaining references cited books, technical reports, and other non-journal sources. In contrast, for the scientific and technical literature as a whole, 80% of all references cite journals.[32] In chemistry, about 90% of references cite journals.[33]

In the master's theses, only 33% of references cited journals. The higher figure of 43% for the Ph.D. dissertations results both from a greater fraction of Ph.D. dissertations than master's theses being in fields with the higher rates of journal citation, and from a ten to fifteen percentage point greater frequency of journal citation in AE, CE, and ME dissertations as compared to theses.

We have seen that the percentage of references which cite journals is

about the same in both master's theses and doctoral dissertations. This rate is far lower than that found in the pure sciences. This may be a cause of concern for some faculty. However, the relatively low percentage of journal citations by both Ph.D. and master's students, and the fact that this result is consistent with characteristics of the engineering and applied science literature as a whole,[32-35] indicates that the the low frequency of journal citation results from a fundamental characteristic of engineering research information sources.

The lesser importance of journals in engineering research as compared, for example, to chemistry, emphasizes the need to make journal selection and cancellation decisions on a subject-by-subject basis.[21] Of more immediate interest at WVU is the fact that the data from the Ph.D. dissertations support the earlier decision to adapt to funding limits by canceling subscriptions rather than by stopping book purchases. Both Ph.D. and master's level engineering research depend on a balanced collection of books, technical reports, and conference proceedings. Librarianship's time-honored response to funding limitations, i. e., protecting the journal subscriptions at the expense of the book collection, is inappropriate in the field of engineering.

Table 3 shows the number of journal citations per dissertation. Note that 3 authors out of 87 did not cite a single journal article, a situation which is unimaginable in the pure sciences. Ten percent of the authors found only 5 or fewer useful articles. The number of doctoral candidates who found very few or no useful journal articles is far less than the 34% of master's students who found no more than a single useful article.

Despite the lesser importance of journals to engineers, one might question the literature searching efforts of students falling at this low end of the journal citation frequency scale. However, it is worth noting that in most cases, those authors who cited fewer than 5 journal articles did cite a total number of sources comparable to the average for their subject areas. Thus, the absence of journal articles relevant to a particular dissertation topic is simply another indication of the relatively low importance of journals in the dissemination of engineering research results.

Journal Titles

The preceeding gives some general feeling for the journal use patterns in engineering. However, only title-by-title citation counts are useful aids in collection development.

Table 4 summarizes some data for individual journal titles. The 87 authors of Ph.D. dissertations cited 585 different journals. Of course, not all of the cited journals are in the field of engineering. Many are in fields as diverse as computer science, medicine, psychology, mathematics, chemistry, and physics. Thus, this table refers to the entire gamut of information needed by engineers, not just to the information found in engineering journals.

Of the 585 journals cited, 288 (49%) received only a single citation

during the seven-year period under study. An additional 16% of the journals received only two citations. The three most highly cited journals provided 10% of all journal citations, and a total of only 51 journals (8.7%) accounted for one-half of the citations to journals.

Table 5 shows the frequency with which journals were cited by different dissertations. Notice that 388 journals, about 2/3 of all journals cited, were cited by only a single author.

These data for citations in Ph.D. dissertations are quite similar to the data for master's theses. In the master's theses also, the three most highly cited journals provided 10% of all journal citations. Half of the master's citations came from 11% of the cited journals. Fully 70% of the journals cited in master's theses were cited by only a single author.

The concentration of citations is typical of distributions found in citation studies of many subject fields using a variety of source documents for citations. It would be helpful if librarians could use these results in a mechanical way to define desirable levels of library service.

Two measures of journal usefulness could be defined using the data in Tables 4 and 5. The first measure would equate usefulness with the total number of citations to a journal title. In this case the librarian would argue that it is desirable to provide as many references as possible for library users. A second measure would define usefulness in terms of the number of individuals who cited a particular journal. In this case the librarian would argue that as many library users as possible should be

satisfied. Thus, a highly cited journal used by only one author would be judged less useful than a less frequently cited journal used by several authors. On examination of the citation data it quickly becomes obvious that such a mechanistic approach is not useful.

Suppose, for example, that we define service levels in terms of the distinctive cut-off points in the tables of citation data. It could then be argued that only those journals which provided three or more citations during the 7 years under study should be included in the collection. Providing the next higher level of service, that is, subscribing to those journals which were cited only twice during 7 years would require a 45% increase in the number of journals available, but these journals would provide only 7% of the citations. It quickly becomes obvious that the resources available in most large libraries, including the WVU libraries, far exceed the amounts necessary to provide such minimal levels of service. To see this we can examine the data in Tables 6 or 7.

Table 6 lists journals in order according to the total number of citations to that title in the 87 dissertations. In Table 7 the journals are listed according to the number of citing authors. With only a few exceptions (those indicated by an "o" before the title), all journals on these lists were represented by at least some holdings in the WVU Libraries. In both lists, titles with an "*" before them are journals purchased in 1979 for the engineering collection at WVU. Titles without this designation are journals in other fields or journals which have ceased publication or changed title (e.g., IEEE Transactions on Electronic Computers changed to IEEE Transactions on Computers, and Industrial and Engineering Chemistry

split into three new journals).

To make discussion manageable, Table 6 lists only those journals cited at least 3 times. Table 7 lists only journals cited in at least three dissertations. We could argue that any journal which provided only one or 2 useful articles in 7 years, or which was found useful by only 1 or 2 authors in that time, is of no more than marginal utility in the engineering research program. Indeed, research journals with such low citation frequencies rank at the level of Time or Newsweek in terms of the number of articles which are related directly to the dissertation topics.

In 1979, WVU subscribed to 345 engineering journals, excluding abstracts and indexes. Of these, only 78 titles were cited three or more times in engineering dissertations during the preceeding 7 years. It should be remembered here that the citation data relate to all the articles that have ever been published in a particular journal. Thus, of all the articles published in American Journal of Mathematics during the past 100 years, only 3 were of direct use to the engineering Ph.D. program during a 7 year period. In accordance with Line's observation,[26] we can assume that chance plays a considerable role in the case of journals cited this infrequently

The citation data make clear that in reducing subscription expenditures to buy books we must make decisions among a large number of journals which are of only marginal utility in terms of supplying articles cited in Ph.D. dissertations. Many journals which are never cited may be of great importance, but there seems to be no valid way in which the citation

data can help us to choose among journals which were cited only once or twice or never by the library users. At best the citation data only calls attention to journals of marginal utility. Choosing among the marginal engineering journals remains very much a matter for judgment by librarians and faculty.

Judgment in building library collections is guided by many rules of thumb. For example, it is accepted among librarians that the mere existence of a Ph.D. program in a subject field requires development of an extensive collection in that subject. Size of the doctoral program is held to be irrelevant, as it is impossible to predict where research might lead and what library materials might be needed. In engineering, then, it would be assumed that far more engineering journals are needed to support the Ph.D. program than the master's program.

At least for journals, this assumption is not supported by the citation data in WVU's graduate engineering programs. At both master's and doctoral levels a small core of engineering journals accounted for the overwhelming majority of citations to engineering journals. The greater number of journals used by doctoral candidates results more from their use of journals in fields other than engineering. Thus, more than half of the journals listed in Table 6 as being cited only 3 to 5 times are not considered to be engineering journals at WVU. A brief examination of these non-engineering titles indicates they are the titles usually thought of as forming the core literature in mathematics, physics, agriculture, and medicine. We can conclude that to support an engineering Ph.D. program it is more important to ensure that the library provides the core literature in

other basic and applied sciences than it is to increase the number of engineering journals beyond the basic core.

The great diversity of sources of information used by engineers demonstrates the benefits of locating an engineering college at a comprehensive university. Clearly WVU engineering students benefit greatly from the presence of WVU's medical school, college of agriculture, and science departments in the college of arts and sciences. Providing this breadth of library support in a more narrowly conceived university or technical college greatly increases the cost per student for library service. Reasons for industry's heavy dependence on university libraries are clearly illustrated also. We can conclude further that in tight budget situations it may be necessary to transfer some library support from a large and flourishing engineering program to maintain purchases of core materials in math and physics. Even when an institution does not have graduate programs in these fields, such purchases may provide more support for engineering than would the purchase of additional engineering subscriptions.

While we cannot conclude that a Ph.D. program in engineering requires more engineering journals than a master's program, neither can we conclude that an engineering master's program requires any less support than a Ph.D. program. This should be kept in mind during the present difficulties in recruiting Ph.D. students. The lack of such students should not be used as an excuse for reducing library support so long as an active master's program is maintained.

Both of these conclusions seem quite logical if we consider that a small engineering Ph.D. program will have only a few students. These will work in only a few subfields of engineering. Most Ph.D. students in this study cited a small range of journals, so a small program could be supported by a relatively small number of journals concentrated in the subfields represented by the few major professors with Ph.D. students. Thus, a small Ph.D. program may require more depth in library support in some subfields, but overall support for the field may be less because the range of research topics in a small program will be limited.

On the other hand, it is quite common in engineering for a relatively large master's program to have no accompanying Ph.D. program. In this case, a wide range of journals might be needed for the master's program, and these journals could easily provide adequate support for a medium-sized Ph.D. program which might be established in the future.

Cost Assignment

Declining purchasing power and demands for accountability have made it necessary for librarians to assign costs of library service to the support of specific programs. Centralized library systems in which all subscription costs were simply subsumed in a single, undifferentiated serials budget have found it necessary to establish numerous separate serials budgets based on subject disciplines. Library systems with

numerous branches have found it necessary to reduce duplicate subscriptions so that only a single subject branch receives the university's sole subscription to a journal.

Some librarians argue that subject assignment of subscriptions is virtually impossible due to the so-called interdisciplinary nature of modern research and teaching. It might be expected that the effects of subject assignment at WVU would be especially troublesome due to the physical separation of the 3 campuses in Morgantown. The citation data provide some assistance in dealing with this question.

Table 8 lists journals cited by Ph.D. candidates in more than one engineering department. Notice that only 10 journals were cited by authors from 4 different departments. Only 16 journals were cited by authors from 3 different departments. Another 87 titles were cited by authors from 2 different departments. Thus, 81% of cited journals were cited by authors from only a single engineering department. Since 96% of the cited journals were of use in no more than 2 departments, we might conclude that there is less evidence than is commonly supposed for intensive multidisciplinary use of journals by engineers.

The citation data indicate that within engineering, most journals are cited only by a single department. Some of the exceptions result from the fact that a few journals are indeed multidisciplinary, Nature being a prime example. In other cases, the multi-department use which does exist is quite predictable in that it results more from the organizational structure of the College of Engineering than from any fundamental multidisciplinary

research. Civil Engineering is a case in point, for the CE Department includes individuals working in several quite different disciplines. The CE department conducts research in air and water pollution (which requires use of some ChE journals), in transportation (which causes some overlap with journals cited by IE students), and in structures (which causes some overlap with ME).

It is clear from Table 8 that only a handful of engineering journals are of direct use in supporting research in more than 1 engineering department. Outside of this small core we find that most engineering journals are of interest to only 1 department. Indeed, only 41 of the engineering journals subscribed to in 1979 had been cited by 2 or more departments.

While there is little multi-department use of engineering journals, a quick perusal of the citation data seems to indicate substantial use by engineers of journals in fields as diverse as medicine, chemistry, mathematics, and physics. Indeed, it is frequently argued that it is inappropriate to attribute the cost of mathematics journals to the mathematics program, or the cost of chemistry journals to the chemistry program, because these journals provide basic support for many other programs, including those in engineering. Indeed, the use by engineers of some core journals in these fields was discussed above.

Careful examination of the citation data indicates that, while engineers do indeed use journals in many non-engineering fields, this use is neither extensive nor intensive. The use is not extensive because rela-

tively few journals from any one non-engineering field are cited. The use is not intensive because most of the non-engineering journals are cited either infrequently or by very few authors. Journals in non-engineering fields which do appear on the lists of frequently cited titles represent only a small fraction of the fundamental core journals in these fields. The overwhelming majority of journals bought to support programs in chemistry or in mathematics or in physics are not cited with any regularity by engineers.

We can conclude that it is a straightforward matter to attribute the costs of journals to particular programs and to shelve particular journals in specific branch libraries. There remains only the question of the degree to which cost attribution or branch assignment will be carried. While distinctions obviously can be made between history and mathematics journals, other distinctions frequently are less obvious. The citation data provide a method of making disciplinary distinctions even among the several subfields of engineering.

The citation data provide support for WVU's practice of distributing journals in several specialized branch libraries, with only very limited duplication of journal subscriptions among the branches. Any confusion about which journals provide primary support for which areas of research arises more from peculiarities of departmental organizations than from any fundamental questions of multidisciplinary use of journals by many different research specialists in many different subject disciplines.

SUMMARY

Citation patterns in WVU engineering Ph.D. dissertations do not differ significantly from patterns found in master's theses. WVU's doctoral engineering students cited journals in only 43% of their references, a journal citation rate which is far lower than rates found in the pure sciences. This relatively low dependence on the journal literature is consistent with the data from the master's theses and with general characteristics of the applied science and engineering literature. The data support WVU's decision to eliminate less useful engineering journal subscriptions in favor of more useful books.

The citation data do not provide a formal mechanism for choosing journals to be retained in the collection. Instead, the data demonstrate that funding for engineering journals far exceeds the amounts needed to purchase the journals which received a significant number of citations. Cancellation decisions involve making choices among a large number of journals which supply few, if any, articles which relate directly to WVU's engineering research. Choosing among these marginal use journals remains very much a matter of judgment on the part of librarians and faculty.

Judgments often are guided by time-honored assumptions. Thus, it is often assumed that a Ph.D. program requires far more engineering journals than does a master's program. However, this assumption is not

supported by the citation data. Conversely, there is no evidence in the citation data to support the contention that master's programs require fewer journals than Ph.D. programs. This last point may be especially significant at a time when engineering schools are having difficulty attracting sufficient doctoral level students to maintain viable Ph.D. programs.

It is clear from the citation data that an engineering Ph.D. program requires maintenance of a core collection of journals in many fields of science. In tight budget situations it will be more important to maintain subscriptions to core journals in mathematics, physics, and chemistry, among others, than to maintain a more extensive list of subscriptions in the field of engineering. This remains true whether or not the parent institution has active research and graduate programs in these related fields.

The citation data show little evidence of extensive multidisciplinary use of engineering journals by engineers. Use of journals across departmental lines is quite limited. Much of what appears to be multidisciplinary use actually results from defining disciplines in terms of the arbitrary departmental distinctions. Thus, the citation data provide a rationale for cost attribution on the basis of disciplines. The data also provide support for locating titles in particular branch libraries with virtually no duplication in other branches.

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Table 1. Statistical summary: Total citations in West Virginia University engineering Ph.D. dissertations.

Department	No. of Dissertations (% of total)	No. of citations (% of total)	Average number of citations per dissertation (range)
Aerospace	8 (9.2%)	308 (5.3%)	38.5 (12- 92)
Chemical	18 (20.7%)	1,862 (31.8%)	103.4 (30-434)
Civil	26 (29.9%)	1,731 (29.5%)	66.6 (12-217)
Electrical	13 (14.9%)	442 (7.5%)	34.0 (15- 63)
Industrial	5 (5.7%)	316 (5.4%)	63.2 (29- 97)
Mechanical	17 (19.5%)	1,201 (20.5%)	70.6 (30-142)
Totals	87 Dissertations	5,860 citations	

Citations per dissertation: Average: 67.4
Median: 58

Table 2. Statistical summary: Journal citations in West Virginia University engineering Ph.D. dissertations.

Department	No. of journal citations (% of total)	% of all citations which cited journals	Journal citations per dissertation (range)	No. of journals cited
Aerospace	79 (3.2%)	25.6%	9.9 (0 - 41)	32
Chemical	964 (38.7%)	51.8%	53.6 (9 - 99)	206
Civil	563 (22.6%)	32.5%	21.7 (0 - 76)	189
Electrical	213 (8.5%)	48.2%	16.4 (6 - 39)	74
Industrial	110 (4.4%)	34.8%	22.0 (10 - 33)	56
Mechanical	565 (22.7%)	47.0%	33.2 (15 - 55)	180
Totals	2,494 journal citations			

The 87 dissertations contained 2,494 citations to 584 different journal titles.

42.6% of all citations were to journals.

Journal citations per dissertation: Average: 28.7

Median: 22.0

Table 3. Distribution of journal citations per dissertation.

Journal citations per dissertation	No. of dissertations	Journal citations per dissertation	No. of dissertations
0	3	27	0
1	1	28	3
2	0	29	3
3	2	30	1
4	2	31	3
5	1	32	2
6	3	33	3
7	2	34	1
8	0	35	0
9	1	37	1
10	3	39	1
11	2	41	3
12	2	43	1
13	2	44	1
14	2	46	1
15	2	51	1
16	3	52	1
17	4	53	1
18	3	55	1
19	2	70	1
20	1	76	1
21	2	81	2
22	1	85	1
23	5	87	1
24	0	90	1
25	0	99	1
26	1	137	1

Table 4. Distribution of citations per journal. A total of 584 different journals were cited.

Citations per journal	No. of journals	(Cumulative no. of journals as % of total)	(Cumulative no. of citations % of total)
1	288	100%	100%
2	92	51%	88%
3	49	35%	81%
4	35		
5	16		
6	18		
7	12		
8	10		
9	7		
10	7	10%	53%
11	7		
12	3		
13	2		
14	3		
15	5		
16	1		
17	1		
18	2	5%	38%
19	7		
20	2		
21	1		
22	1		
23	2		
24	2		
28	1		
30	1		
32	1		
37	2		
41	1		
44	1	1%	16%
56	1		
59	1		
74	1		
82	1		
95	1		
	585 journals	3 dissertations cited no journals	

Table 5. Distribution of dissertations per journal.

No. of citing dissertations	No. of journals
1	388
2	94
3	40
4	22
5	10
6	10
7	6
8	5
9	1
10	3
11	2
12	2
13	1
18	1
	585

66% of journals were used by only 1 author.

82% were used by 2 or fewer.

89% of journals were cited by 3 or fewer individuals.

Table 6. Journals listed in rank order according to the total number of citations in West Virginia University Engineering dissertations. (* = 1979 WVU engineering subscription).

Total Citations	Title (Number of authors citing the title)
95	Industrial and Engineering Chemistry (18)
82	*AIChE Journal (13)
74	Fuel (10)
59	*Chemical Engineering Science (12)
56	*Journal of Applied Mechanics (11)
44	*American Concrete Institute. Journal (7)
41	*Environmental Science & Technology (8)
37	Carbon (3) *Journal of Fluid Mechanics (12)
32	*ASCE. Structural Division. Journal (8)
30	*Water Pollution Control Federation. Journal (7)
28	IEEE Transactions on Electronic Computers (4)
24	*AIAA Journal (7) *I&EC Fundamentals (11)
23	*Ergonomics (2) Institute of Fuel. Journal (8)
22	*Journal of Biomechanics (5)
21	Chemical Society. London. Journal (10)

Total Citations	Title (Number of authors citing the title)
20	*Canadian Journal of Chemical Engineering (8)
	*Prestressed Concrete Institute. Journal (1)
19	ASCE. Sanitary Engineering Division. Journal (5)
	American Chemical Society. Journal (19)
	*Analytical Chemistry (4)
	Circulation Research (3)
	*Civil Engineering (ASCE) (3)
	Coal Mining and Processing (2)
	*IEEE Transactions on Computers (4)
18	ASME Transactions (6)
	*IEEE Transactions on Power Apparatus and Systems (2)
17	*I&EC Process Design and Development (10)
16	Nature (6)
15	*Chemical Engineering (7)
	Computer Journal (5)
	Faraday Society. Transactions (8)
	*Journal of Basic Engineering (4)
	Journal of Physical Chemistry (6)
14	American Journal of Physiology (5)
	Journal of Applied Physics (9)
	Journal of Bacteriology (2)
13	*Nuclear Science and Engineering (1)
	Society of Petroleum Engineers. Journal (4)
12	Journal of Petroleum Technology (3)
	Kagaku Kogaku (3)
	*Management Science (5)
11	American Leather Chemists Association. Journal (1)
	*Chemical Engineering Progress (6)
	*IEEE Transactions on Reliability (1)
	*Institution of Chemical Engineers. Transactions (6)
	Journal of Chemical Physics (7)
	Science (6)
	Soil Science (4)

Total Citations	Title (Number of authors citing the title)
10	*ASCE. Engineering Mechanics Division. Journal (6)
	*Aeronautical Quarterly (4)
	*American Water Works Association. Journal (5)
	Biophysical Journal (4)
	*Biorheology (3)
	*Chemical and Engineering News (1)
	Quarterly of Applied Mathematics (6)
9	AIME Transactions (3)
	American Institute of Planners. Journal (4)
	*IEEE Proceedings (6)
	*International Chemical Engineering (3)
	International Journal of Rock Mechanics & Mining Sciences (2)
	Journal of Applied Physiology (7)
	Soil Science Society of America. Proceedings (1)
8	American Journal of Public Health (2)
	British Medical Journal (1)
	Colliery Engineering (3)
	*Compost Science (1)
	*Engineering News Record (2)
	*IEEE Transactions on Communications (1)
	*IEEE Transactions on Information Theory (3)
	*International Journal of Engineering Science (5)
	Journal of the Aerospace Sciences (3)
	SIAM Journal (4)
7	*ASCE. Hydraulics Division. Journal (5)
	*Aeronautical Journal (3)
	Biochemical Journal (2)
	British Journal of Surgery (1)
	*Chemical Engineering Journal (Japan) (2)
	*International Journal of Solids and Structures (6)
	IRE Proceedings (3)
	Journal of Bone and Joint Surgery (1)
	Journal of Mechanics and Physics of Solids (2)
	Separation Science (2)
	Society of Rheology. Transactions (1)
	*Water Resources Research (3)

Total Citations	Title (Number of authors citing the title)
6	*ASCE. Environmental Engineering Division. Journal (2)
	*Acier. Stahl. Steel (1)
	*Air Pollution Control Association. Journal (3)
	*Applied Scientific Research (4)
	*Archive for Rational Mechanics and Analysis (4)
	*Association for Computing Machinery. Journal (5)
	Brennstoff Chemie (4)
	British Journal of Applied Physics (3)
	Journal of Chromatography (1)
	*Journal of Engineering for Power (2)
	Journal of Neurophysiology (1)
	Lancet (1)
	Prikladnia Matematika I Mekhanika (2)
	*Radio Science (3)
	Royal Society (London). Proceedings A (3)
	Teploenergetika (6)
	Traffic Engineering (3)
	*Water and Sewage Works (4)
5	*Acoustical Society of America. Journal (4)
	Compte Rendus (l'Academie des Sciences, Paris) (4)
	Engineering Journal of the AISC (4)
	Experimental Neurology (1)
	Forest Products Journal (2)
	*IEEE Transactions on Antennas and Propagation (3)
	*Journal of Heat Transfer (3)
	Journal of Mathematical Physics (2)
	Journal of Physiology (2)
	Journal of Soil and Water Conservation (5)
	Kinetika I Kataliz (1)
	Microvascular Research (1)
	*Operations Research (4)
	*Public Roads (2)
	*Der Stahlbau (1)
	*Structural Engineer (1)

Total Citations	Title (Number of authors citing the title)
4	ASCE. Soil Mechanics and Foundations Division. Journal (2)
	Acta Orthopaedica Scandinavica (2)
	Agronomy Journal (1)
	American Mathematical Society. Bulletin (4)
	Anatomical Record (2)
	Applied Microbiology (92)
	Behavioral Science (3)
	Biometrics (2)
	Cambridge Philosophical Society. Proceedings (4)
	Chemical and Process Engineering (1)
	Chemistry and Industry (3)
	*Electrical World (3)
	Electrochemical Society. Journal (1)
	*Franklin Institute Journal (4)
	Gazovaya Promyshlennost (2)
	*IEEE Spectrum (4)
	*IEEE Transactions on Biomedical Engineering (2)
	IEEE Transactions on Communication Technology (1)
	*International Journal of Heat and Mass Transfer (3)
	Journal of Biological Chemistry (2)
	Journal of Catalysis (1)
	Journal of Colloid Science (2)
	Journal of Experimental Psychology (1)
	Journal of Gas Chromatography (1)
	Journal of Geophysical Research (3)
	*Mechanical Engineering (3)
	Medical and Biological Engineering (3)
	Philosophical Magazine (3)
	Sewage and Industrial Wastes (2)
	Society of Mechanical Engineers (Japan). Transactions (1)
	Society of Mining Engineers of AIME. Transactions (3)
	Steel and Coal (2)
	Westinghouse Engineer (3)
	Zeitschrift fur Angewandte Matematik und Mekhanik (2)
	Zeitschrift fur Naturforschung. Teil A (3)

Total Citations	Title (Number of authors citing the title)
3	ASCE. Construction Division. Journal (1)
	American Journal of Mathematics (2)
	American Journal of Physical Medicine (2)
	American Laboratory (1)
	American Society of Agricultural Engineers. Transactions (2)
	Annalen der Physik (2)
	Berichte der Deutschen Chemischen Gesellschaft (1)
	Chemical Reviews (3)
	Chemical Technology (3)
	Chromatographia (1)
	Coal Age (2)
	Combustion and Flame (2)
	Gas Journal (2)
	*Harvard Business Review (2)
	*Hydrocarbon Processing (2)
	Ingenieur-Archiv (2)
	Institute of Mining and Metallurgy. Transactions (1)
	International Journal of Fracture Mechanics (1)
	IRE Transactions on Antennas and Propagation (2)
	*Journal of Aircraft (1)
	Journal of Applied Bacteriology (2)
	Journal of Applied Chemistry (3)
	*Journal of Chemical Engineering of Japan (3)
	Journal of Colloid and Interface Science (1)
	*Journal of Composite Materials (2)
	*Journal of Engineering Materials and Technology (1)
	*Journal of Fluids Engineering (1)
	Journal of General Physiology (1)
	Journal of Inorganic and Nuclear Chemistry (2)
	*Journal of Mechanical Engineering Science (1)
	Journal of the Kyoto Prefectural University of Medicine (1)
	Journal of the Science of Food and Agriculture (2)
	Mathematical Society (London). Proceedings (2)
	Measurement and Control (1)
	National Bureau of Standards. Journal of Research (2)
	*Naval Research Logistics Quarterly (2)
	Oil and Gas Journal (1)
	Physical Society of Japan. Journal (2)
	Physics of Fluids (2)
	Psychosomatic Medicine (1)
	*Public Works (3)
	Recueil des Travaux Chimiques des Pays-Bas (2)
	Scientific American (2)
	South African Institute of Mining and Metallurgy (1)
	Tappi(2)
	Tohoku Imperial University Technology Reports (2)
	Zeitschrift fur Angewandte Chemie (3)
	Zeitschrift fur Anorganische Chemie (3)
	Zeitschrift fur Physikalische Chemie (3)

Table 7. Journals listed in rank order according to the number of authors citing the journal in West Virginia University Engineering dissertations (* = 1979 WVU engineering subscription).

No. of Authors	Title
18	Industrial and Engineering Chemistry
13	*AIChE Journal
12	*Chemical Engineering Science *Journal of Fluid Mechanics
11	I&EC Fundamentals *Journal of Applied Mechanics
10	Chemical Society. London. Journal Fuel *I&EC Process Design and Development
9	Journal of Applied Physics
8	*ASCE. Structural Division. Journal *Canadian Journal of Chemical Engineering *Environmental Science & Technology Faraday Society. Transactions Institute of Fuel. Journal
7	*AIAA Journal *American Concrete Institute. Journal *Chemical Engineering Journal of Applied Physiology Journal of Chemical Physics *Water Pollution Control Federation. Journal
6	*ASCE. Engineering Mechanics Division. Journal ASME Transactions *Chemical Engineering Progress *IEEE Proceedings *Institution of Chemical Engineers. Transactions *International Journal of Solids and Structures Journal of Physical Chemistry Nature Quarterly of Applied Mathematics Science

No. of Authors	Title
5	*ASCE. Hydraulics Division. Journal
	ASCE. Sanitary Engineering Division. Journal
	American Chemical Society. Journal
	American Journal of Physiology
	*American Water Works Association. Journal
	*Association for Computing Machinery. Journal
	Computer Journal
	*International Journal of Engineering Science
	*Journal of Biomechanics
	*Management Science
4	*Acoustical Society of America. Journal
	*Aeronautical Quarterly
	American Institute of Planners. Journal
	American Mathematical Society. Bulletin
	*Analytical Chemistry
	*Applied Scientific Research
	*Archive for Rational Mechanics and Analysis
	Biophysical Journal
	Brennstoff Chemie
	Cambridge Philosophical Society. Proceedings
	Compte Rendus (l'Academie des Sciences, Paris)
	Engineering Journal of the AISC
	*Franklin Institute Journal
	*IEEE Spectrum
	*IEEE Transactions on Computers
	IEEE Transactions on Electronic Computers
	*Journal of Basic Engineering
	*Operations Research
	SIAM Journal
	Society of Petroleum Engineers. Journal
	Soil Science
	*Water and Sewage Works

No. of Authors	Title
3	AIME Transactions
	*Aeronautical Journal
	*Air Pollution Control Association. Journal
	Behavioral Science
	*Biorheology
	British Journal of Applied Physics
	Carbon
	Chemical Reviews
	Chemical Technology
	Chemistry and Industry
	Circulation Research
	*Civil Engineering (ASCE)
	Colliery Engineering
	*Electrical World
	*IEEE Transactions on Antennas and Propagation
	*IEEE Transactions on Information Theory
	IRE Proceedings
	*International Chemical Engineering
	*International Journal of Heat and Mass Transfer
	Journal of Applied Chemistry
	*Journal of Chemical Engineering of Japan
	Journal of Geophysical Research
	*Journal of Heat Transfer
	Journal of Petroleum Technology
	Journal of the Aerospace Sciences
	Kagaku Kogaku (Japan)
	*Mechanical Engineering
	Medical and Biological Engineering
	Philosophical Magazine
	*Public Works
	*Radio Science
	Royal Society (London). Proceedings A
	Society of Mining Engineers. Transactions
	Traffic Engineering
	*Water Resources Research
	Westinghouse Engineer
	Zeitschrift fur Angewandte Chemie
	Zeitschrift fur Anorganische Chemie
	Zeitschrift fur Naturforschung. Teil A
	Zeitschrift fur Physakalische Chemie

Table 8. Journals which were cited by authors from more than one engineering department. (* = 1979 WVU engineering subscription).

The following 10 journals were cited by authors from four different departments:

Total Citations	Title (Number of authors citing the title)
95	Industrial and Engineering Chemistry (18)
56	*Journal of Applied Mechanics (11)
37	*Journal of Fluid Mechanics (12)
21	Chemical Society. London. Journal (10)
15	*Chemical Engineering (7) Computer Journal (5)
14	Journal of Applied Physics (9)
7	*ASCE. Hydraulics Division. Journal (5)
6	*Applied Scientific Research (4) *Association for Computing Machinery. Journal (5)

The following 16 journals were cited by authors from three different departments:

Total Citations	Title (Number of authors citing the title)
82	*AIChE Journal (13)
30	*Water Pollution Control Federation. Journal (7)
24	*AIAA Journal (7)
17	*I&EC Process Design and Development (10)
16	Nature (6)
15	*Journal of Basic Engineering (4)
14	American Journal of Physiology (5)
9	Journal of Applied Physiology (7)
8	Journal of the Aerospace Sciences (3) SIAM Journal (4)
6	Royal Society (London). Proceedings A (3)
5	*Journal of Heat Transfer (3)
4	American Mathematical Society. Bulletin (4) *Electrical World (3) *Franklin Institute Journal (4) Zeitschrift fur Naturforschung. Teil A (3)

The following 87 journals were cited by authors from two different departments.

Total Citations	Title (Number of authors citing the title)
41	*Environmental Science & Technology (8)
32	*ASCE. Structural Division. Journal (8)
23	*Ergonomics (2) Institute of Fuel. Journal (8)
20	*Canadian Journal of Chemical Engineering (8)
19	ASCE. Sanitary Engineering Division. Journal (5) American Chemical Society. Journal (19) *Analytical Chemistry (4)
18	ASME Transactions (6) *IEEE Transactions on Power Apparatus and Systems (2)
15	Faraday Society. Transactions (8) Journal of Physical Chemistry (6)
14	Journal of Bacteriology (2)
12	*Management Science (5)
11	Journal of Chemical Physics (7) Science (6)
10	*ASCE. Engineering Mechanics Division. Journal (6) *American Water Works Association. Journal (5) Biophysical Journal (4) Quarterly of Applied Mathematics (6)
9	AIME Transactions (3) American Institute of Planners. Journal (4) *IEEE Proceedings (6)
7	*Aeronautical Journal (3) Biochemical Journal (2) *International Journal of Solids and Structures (6) IRE Proceedings (3) *Water Resources Research (3)

Total Citations	Title (Number of authors citing the title)
6	*Air Pollution Control Association. Journal (3)
	Brennstoff Chemie (4)
	British Journal of Applied Physics (3)
	*Journal of Engineering for Power (2)
	Prikladnia Matematika I Mekhanika (2)
	Traffic Engineering (3)
5	*Acoustical Society of America. Journal (4)
	Compte Rendus (l'Academie des Sciences, Paris) (4)
	Journal of Mathematical Physics (2)
	Journal of Physiology (2)
	*Operations Research (4)
4	Applied Microbiology 92)
	Behavioral Science (3)
	Biometrics (2)
	Cambridge Philosophical Society. Proceedings (4)
	*IEEE Spectrum (4)
	*IEEE Transactions on Biomedical Engineering (2)
	*International Journal of Heat and Mass Transfer (3)
	Journal of Biological Chemistry (2)
	Journal of Colloid Science (2)
	Journal of Geophysical Research (3)
	*Mechanical Engineering (3)
	Medical and Biological Engineering (3)
	Philosophical Magazine (3)
	Sewage and Industrial Wastes (2)
	Society of Mechanical Engineers (Japan). Transactions (1)
	Westinghouse Engineer (3)
	Zeitschrift fur Angewandte Matematik und Mekhanik (2)
3	American Journal of Mathematics (2)
	Annalen der Physik (2)
	Combustion and Flame (2)
	Ingenieur-Archiv (2)
	IRE Transactions on Antennas and Propagation (2)
	Journal of Applied Bacteriology (2)
	*Journal of Chemical Engineering of Japan (3)
	Mathematical Society (London). Proceedings (2)
	*Naval Research Logistics Quarterly (2)
	Physical Society of Japan. Journal (2)
	*Public Works (3)
	Scientific American (2)
	Tappi(2)
	Zeitschrift fur Physikalische Chemie (3)

Total Citations	Title (Number of authors citing the title)
2	American Mathematical Society. Transactions (2)
	Applied Statistics (2)
	*Aviation Week and Space Technology (2)
	Colliery Guardian (2)
	Federation Proceedings (2)
	IEEE Transactions on System Science and Cybernetics (2)
	Interfaces (2)
	*International Journal of Nonlinear Mechanics (2)
	Journal of Mathematics and Physics (2)
	Metropolitan Transportation and Planning (2)
	Nuclear News (2)
	Personal Rapid Transit Biweekly (2)
	Physics (2)
	Popular Science (2)
	*Power Engineering (2)
	Reviews of Modern Physics (2)
	*Transportation Engineering Journal of the ASCE (2)